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J. P. Curtis, A. G. Jones, C. T. Hughes, J. E. Reaugh

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MODELLING VIOLENT REACTION FOLLOWING LOW SPEED IMPACT ON CONFINED EXPLOSIVES

J. P. Curtis[1], A. G. Jones[1], C. T. Hughes[1], and J. E. Reaugh[2]

[1]*AWE Aldermaston, Reading, RG7 4PR, UK*
[2]*LLNL, Livermore, CA 94551, USA*

Abstract. To ensure the safe storage and deployment of explosives it is important to understand the mechanisms that give rise to ignition and reaction growth in low speed impacts. The High Explosive Response to Mechanical Stimulus (HERMES) material model, integrated in the Lagrangian code LS-DYNA, has been developed to model the progress of the reaction after such an impact.

The low speed impact characteristics of an HMX based formulation have been examined using the AWE Steven Test. Axisymmetric simulations of an HMX explosive in the AWE Steven Test have been performed. A sensitivity study included the influence of friction, mesh resolution, and confinement. By comparing the experimental and calculated results, key model parameters which determine the explosive's response in this configuration have been identified. The model qualitatively predicts the point of ignition within the vehicle. Future refinements are discussed.

Keywords: Low speed impact, high explosive, violent reaction, Steven Test, friction, ignition.
PACS: 46.35.+z, 47.11.Fg, 47.40.-x, 82.40.Fp.

INTRODUCTION

To assess the safety of explosives, whether they are in unconfined charges or in a weapon system, it is essential to understand and be able to predict the threshold and subsequent violence of reaction to mechanical (low speed impact) insults. Predicting the response of explosives to mechanical stimuli is very challenging due to the range of mechanisms that could determine the ignition and growth of reaction. Reactions can vary from no visible response, through increasingly violent responses where some, but not all, of the explosive explodes (the so-called High Explosive Violent Response, HEVR), to, potentially, detonation.

Recently, a model for predicting HEVR called HERMES (High Explosive Response to MEchanical Stimulus) has been developed [1,2]. HERMES has been implemented as a material model in the Lagrangian LS-DYNA Finite Element (FE) code [3].

This paper briefly describes the HERMES model and its application to the AWE Steven Test. The axisymmetric test vehicle lends itself to FE modelling with LS-DYNA. The results of experiments are compared with theoretical predictions and the effects of varying model parameters and coefficients on the ignition of the modelled explosive are explored.

BACKGROUND

The HERMES Model

The HERMES model comprises several sub models including a constitutive model for strength, a model for damage that includes the creation of porosity and surface area through fragmentation, an ignition model, an ignition front propagation model, and a model for burning after ignition. Note that thermal effects are not yet explicitly modelled. In the model, ignition is based on a purely mechanical criterion depending on a time integral of a function of the shear, equivalent stress, pressure and strain rate as follows:

$$I_{gn} = \int_0^t \left(2 - \frac{27|s_1 s_2 s_3|}{2Y^3} \right)^5 \left(\frac{p + s_2/2}{P_0} \right)^{1/2} \dot{\varepsilon}_p \, dt \tag{1}$$

Here $s_{1,2,3}$ are the principal stress deviators, Y is the equivalent stress, p is the pressure, P_0 is a prescribed constant value of pressure, and $\dot{\varepsilon}_p$ is the plastic strain rate. Ignition is deemed to commence when I_{gn} reaches a particular value. That value will of course vary from explosive to explosive and is calibrated by undertaking experiments. Further details are given by Reaugh [4]. There is some similarity with the approach of Gruau *et al.* [5], in which a different history integral is used. The model is presently implemented as a material model in the Livermore Software Technology Co. finite element code LS-DYNA. Currently the model is being used for axisymmetric configurations using the traditional shell elements offered by LS-DYNA, but it has also been applied to full three-dimensional analyses.

The Steven Test

The AWE Steven Test is used to assess the response of explosive to low speed impact. The test configuration is shown in Figure 1.

The test comprises a 70 mm diameter by 12.7 mm thick explosive disc with a 10 mm (radial) thick PTFE ring surrounding it. These are located inside a steel base unit, which provides a high level of confinement both radially and to the rear of the explosive. A 3 mm thick steel cover plate is located on top of the target providing full confinement to the explosive sample.

The cover plate is secured to the base unit by a steel strong ring bolted to the target stand plate. A 1.6 kg round nosed 50 mm diameter cylindrical steel projectile is fired at the centre of the cover plate of the target vehicle from a gas gun. The

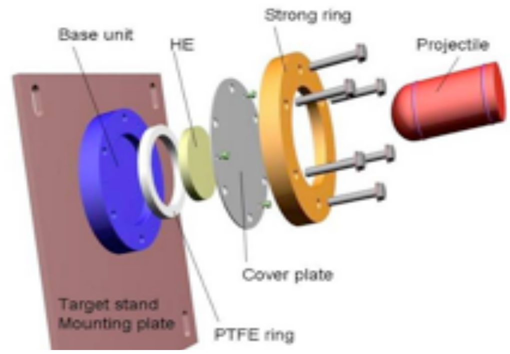

Figure 1. The AWE Steven Test Configuration

impact velocity of the projectile is varied to determine the threshold for reaction of the explosive being tested.

At impact velocities below the critical velocity for a HEVR the vehicle will remain intact; with a volume of the explosive near the impact region being damaged. This manifests itself as surface area through cracking and fragments. As the impact velocity increases, the degree and extent of damage increase. The steel cover plate deforms to allow the material to flow out of the impact region. As the impact velocity is increased closer to the critical ignition velocity scorching becomes evident in the cracks formed. This is the onset of ignition. At higher speeds these areas of ignition can coalesce leading to localised burning; which can then spread through the cracked damaged material bed. The flame burn speed is controlled by the internal pressure and amount of surface area. If the internal pressure exceeds the vehicle confinement strength then the vehicle will disrupt, the sudden loss of confinement quenching the reaction. If the confinement holds for a long enough period or the reaction rate is high then a large violent reaction is seen. It is therefore possible to traverse a wide range of violent reaction with a small range of velocities containing the HEVR threshold.

EXPERIMENTAL

In the AWE Steven Test with the explosive under consideration, the projectile impact velocity threshold to give reaction is about 63 $m.s^{-1}$ (± 3 $m.s^{-1}$).

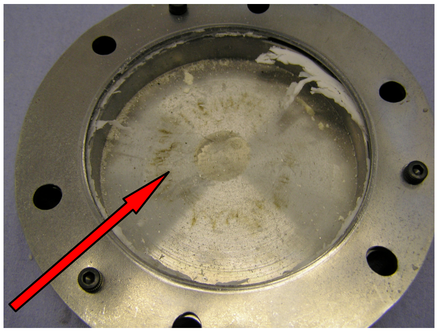

Figure 2. The test vehicle base unit following an HEVR event showing an annular discoloured region (arrowed), around the impact site where the reaction has marked the base.

Figure 2 shows the base unit of a test vehicle following a typical HEVR event after the projectile impacted the target at 84 $m.s^{-1}$. The explosive partially reacted, with the remaining unconsumed explosive together with most of the PTFE ring ejected from the test vehicle.

There is evidence of scorching around the impact region on the test vehicle base unit which has been seen on base units from other tests that produced HEVR.

MODEL PREDICTIONS

The Cubit mesh generation tool [6] was used to create an axisymmetric model of the AWE Steven Test and the export file is edited using LS-DYNA keywords to enable the precise specification of initial conditions, boundary conditions, and constraints.

A range of simulations have been performed which varied the velocity of the projectile, mesh size, confinement and friction coefficient.

Figure 3 shows the deformation of the explosive in the test vehicle as a result of an impact by the projectile at 70 m/s. The confinement was originally modelled by clamping the strong ring to the cover plate and cup but in more recent runs it is held in place by an axisymmetric representation of the six bolts, with negligible change in the calculated results.

With the ignition criterion set to a value of 190 and friction coefficient set to a nominal value of 0.4 following Hoffman and Chandler [7], the onset of ignition due to extreme shear and material deformation is shown in Figure 4. The model predicts the onset of ignition in an annular region similar to those seen in experiments, Figure 2. Shortly after this time the run failed due to distortion of the mesh.

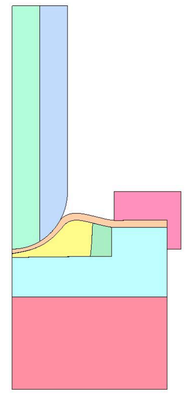

Figure 3. Deformation of the UK Steven Test configuration resulting from a 70 m/s projectile impact, just prior to cessation of the run caused by severe mesh entanglement.

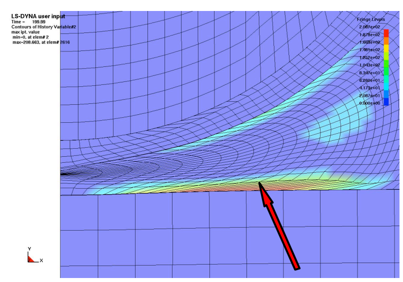

Figure 4. Detail of the situation depicted in Figure 3, showing the extreme shear distortion of the mesh with accompanying high values of the ignition parameter in the igniting explosive at a radius of approximately half that of the projectile from the axis of symmetry (arrowed).

Figure 5 shows how the maximum value of the ignition parameter anywhere in the explosive, which is the value believed to be significant in determining the response, varies as the friction coefficient is changed from the nominal value of 0.4.

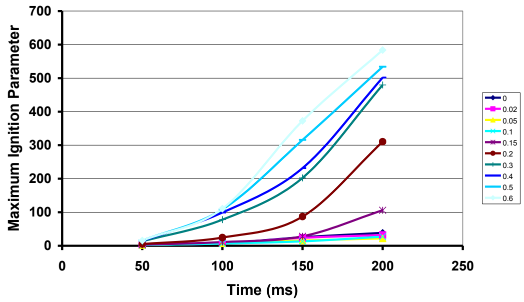

Figure 5. Maximum value of ignition parameter in explosive as a function of time and friction coefficient.

There is clearly broadly monotonic behaviour with respect to the friction coefficient and it is probable that local variation in the friction coefficient will influence the response of the explosive.

A limited mesh sensitivity study has examined the dependence of the displacement of the front surface of the base unit on the axis of symmetry to cell size in the explosive and shows convergence.

DISCUSSION

The ignition criterion of the HERMES model appears to offer a very promising, physically motivated, mechanical criterion for ignition in the Steven Test configuration.

There is a monotonic increase in ignition parameter with impact speed, enabling the critical velocity for ignition to be associated with the critical ignition parameter. The dependence of the critical value for a given explosive on the experimental geometry will be investigated. We have predicted that the response in the Steven Test configuration is heavily dependent on the coefficient of friction used. The means of representing the strong ring securing bolts has negligible effect on the highest values of the ignition parameter generated. The results for the base unit deformation on the axis of symmetry converge as the mesh cell size is decreased.

The abilities to track interfaces accurately and to model friction are important advantages of the Lagrangian formulation. It is therefore unfortunate that, under circumstances where ignition occurs, the problem of mesh distortion with a purely Lagrangian formulation is a significant one. Nonetheless, it is emphasised that the Lagrangian model can be used to make good predictions until distortion causes failure and thus it should be useful for verification of other formulations at early times.

There are alternative approaches to addressing the problem of mesh distortion. First, it may be possible to use the Smoothed Particle Hydrodynamics (SPH) capability within LS-DYNA itself.

HERMES is also being incorporated in the LLNL Arbitrary-Lagrange-Eulerian code ALE3D. This should offer an independent means of treating the extreme deformations.

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